backup generators (and some UPS systems), interruptions of mains power to the transmitter sufficient to cause shutdown will occur from time to time. In some of these cases, klystron damage can occur for the following reasons:

* Because of a mechanical and/or electrical malfunction of the main circuit breaker, it remains closed when power is lost. When power resumes, full operation returns to the transmitter all at once, meaning that high voltage is applied to the klystrons before the magnet supply can provide adequate beam focusing. This allows full beam power to be dissipated in the klystron body, thereby melting the drift tubes.

* In some transmitters, the time constant of one subsystem's power supply filtering may differ significantly from another. These varying time constants will cause each power supply to exhibit a different discharge time when mains power is removed. If the focusing electromagnet supply has no filter capacitance, it will discharge almost instantly, while the klystron's beam-filtering circuitry allows the high voltage to ramp off relatively slowly. Again, this defocuses the beam, dissipating its remaining power into the drift tubes and melting them.

* Some transmitters run their focusing magnets and protection circuits from the same leg of the incoming 3-phase power, and their high-voltage supply on another phase. If only the first phase is lost, and the low-voltage sensing relay of the main breaker is misadjusted or not working, the high voltage will stay on, but the focusing and protection circuits will shut down. Once again, beam defocus will occur, and the tube body will melt.

Recommended Countermeasures

There are several procedures to prevent these problems. First, regular testing of the main breaker should be performed. Use the transmitter control function and a mains power interruption to fully test the breaker's performance. Because most power outages are a seasonal phenomenon, inspection and servicing the breaker just before each year's prime outage period is a good idea. If a particularly high number of outages are experienced, more frequent breaker service is recommended.

Next, check the discharge times of the filtering in the beam and magnet power supplies. Capacitance should be added to the magnet supply if its time constant is less than that of the beam supply. Use computer-grade electrolytic caps with adequate voltage ratings.

Vacuum relays can also be installed on each high-voltage power leg, between the main breaker and the high-voltage supply. This will prevent the instantaneous high-voltage return problem previously mentioned in the first breaker failure scenario. The primary or low-voltage circuit configuration of these relays should prevent relay reclosure before the focusing magnet's field has fully built back up, upon restoration of mains power. If it is not already provided, a loss-of-leg sensor should be installed, to prevent the single phase drop problem mentioned earlier from occurring.

A further refinement involves the installation of an undercurrent-sensing interlock on the focusing magnet supply. this will avoid the premature restoration of high voltage to klystrons before focusing magnets have returned to full field strength; it will also shut down the high voltage if the magnet's supply current falls below this level at any time.

24. Water and Storage

Before putting a spare klystron away for storage, its water line should be drained thoroughly, and then blown dry. Any water - even distilled water - that remains in a klystron's cooling passages over extended periods can cause corrosion. If the klystron is stored in a place where it is exposed to freezing temperatures, physical damage could also occur from any residual water's expansion.

When draining an internal-cavity klystron, place it in a horizontal position, with its tuner facing downward. All klystrons should be kept will covered while in storage to prevent any accumulations of dirt or moisture on its surfaces.

Summary

Whenever I hear someone comment that they feel there is not enough to do to justify a full weekly transmitter maintenance period, I must strongly take issue with them. Another school of thought held by some is; "if it ain't broke, don't fix it!" In this it is felt that more problems are created by rummaging around inside the cabinets than by leaving well enough alone when the transmitter is running. My response to those who hold this opinion is that if attempts at performing routine maintenance has created that many problems for them in the past, some serious effort should be given in determining why. A properly operating system must allow full access.

The long term reliability, efficiency and F.C.C. Rules compliance of any transmitter is, in the final analysis, directly attributable to a properly and staunchly performed routine maintenance program. The following pages are a summary checklist of the salient items I have discussed. You might use them as a guide against which you can map out your own scheduled maintenance program. The items will be categorized by suggested time intervals.

Following the suggested schedule section will be additional information in areas which will hopefully be useful in troubleshooting transmitter and tube problems. Possibly something you read may assist you some day in locating or heading off a problem area in your system.

Weekly Requirements

1. Operating Conditions

A. Prior to sign-off compare current readings with the week's logged readings.

2. Cleaning

A. Vacuum and dust inside cubicles.
B. Mop floor.
C. Inspect air filters; blow out and replace as required.
D. Check for dust leaks.

3. Water System

A. Check reservoir level.
B. Inspect water for foaming, discoloration and contamination.
C. Observe flow rates and temperatures before sign-off. Compare with previous observations.
D. Visually inspect all plumbing.
E. Observe cold start-up of system - check for leaks.
F. If filter system prone to frequent contamination, check weekly and change bag as necessary. Otherwise quarterly.

4. R.F. System

A. Feel and inspect output stacks, output couplers and cavities before sign-off.
B. Inspect RF system for hot spots, discoloration or melting.
C. Check line pressure.
D. Check dehydrator duty cycle (or nitrogen loss rate).
E. Check all connecting leads in the electron gun region for condition and that they are properly tightened.
D. Inspect RF cables for condition (i.e. no melting has occurred due to high temperatures).
E. Check that cavity loads are in good order and no oil leaks.

5. Klystron Beam Power Supplies

A. Check indicated oil level.
B. Inspect for oil leaks.
C. Check terminal boxes (i.e. no water leaks, corrosion).
D. Check nitrogen pressure (Aydin supplies)

6. Exciter System

A. Frequency checks; aural, visual, intercarrier compare your measuring equipment with outside traceable source (if possible).

7. System Sweep

A. Stations with spectrum analyzers; sweep weekly - log results.

9. High Voltage Beam Contactors

A. Observe for proper operation during protection circuits check.

10. Arc Detectors

A. Exercise test mode.

11. Remote Control Meter Calibration

A. Perform weekly to within 2 %.

12. Waveform Analysis

A. Pulsed transmitters; check transmitted waveform for pulser induced waveform distortions with attention paid to vertical sync and equalizing pulses.
B. Run through full field test waveforms observe for unacceptable distortions in;

- Differential Gain
- Differential Phase
- Incidental Phase
- Envelope Delay
- 12.5T and 2T Pulse Response
- Multiburst (baseband frequency response)

Also observe timing and amplitudes of all significant sync, blanking chrominance, subcarrier (etc.) parameters.

C. Check depth of modulation (spectrum analyzer and/or demodulator).

13. Transmitter Protection Circuits

A. Disable high voltage supply to klystron (usually by shutting off high voltage power supply circuit breaker) then check;

* Magnet Current Loss Trip
* Body Current Trip (not by actually inducing condition)
* Beam Overvoltage Trip
* Overtemperature Trip
* Arc Detector Trip
* Water Flow Trip
* Power Line Phase Loss Trip
* VSWR Trip
* Filament Current Fault Trip
* "Test"/"Lamp Test"/"Reset" modes; replace lamps

Also check any other critical function trips not mentioned which are significant to your transmitter.

14. System Meter Checks

A. Note value of all readings, compare with klystron specifications.
B. Immediately repair all defective meter or driver circuits.
C. Calibrate filament voltage meter by measuring that actually read across filament terminals with digital volt meter.

16. Lubrication - Belts - Hoses

A. Lubricate as needed.
B. Inspect belts, hoses replace as needed.
C. Measure resistance in collector hoses if body current reading abnormally high with no other explanation.

17. Parts - Tools Inventory

A. Organize, inventory and order as required.

18. Inspection of Premises

A. Inside;

* Condition of transmitter cabinets
* Clean up temporary or unsafe wiring
* Police up storage and work areas
* Haul off trash

B. Outside;

* Grass, weeds, pest control
* Inspect fence
* Inspect exterior paint
* Intrusion alarm check
* Check for signs of forced entry
* Check for unrepaired ice damage roofs, heat exchangers

19. Tower

A. Obstruction light check (eyeball).
B. Cursory structural check (any obvious problems).

Quarterly Requirements

2. Cleaning

A. Wipe down circuit assemblies with dry cloth or paper towels.
B. Clean tube and beam supply ceramic standoffs with Isopropyl Alcohol or Freon T F.

3. Water System

A. pH check 6.0 - 8.0 distilled water only, with SR-1, 9.0 - 9.6 (50% solution). also perform conductivity check.
B. Inspect filter system bag and change if necessary.
C. Inspect heat exchanger core for any necessary cleaning.

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4. R.F. System

A. Collector/Body resistance check.

5. Exciter System

A. Stations without spectrum analyzers; borrow one and sweep system - logs results and required adjustments.

7. System Sweep

A. Perform resistance check on cavity loads.

8. Aural Carrier Deviation Check

A. Check aural deviation with spectrum analyzer Bessel function; also calibrate modulation monitors.

15. Power Calibration

A. Perform power calibration; mark or reset meters; log results.

19. Tower

A. Quarterly tower inspection - log results and any actions taken.

Six Month Interval

2. Water System

A. Flush and summerize/winterize at beginning and end of winter.
B. Perform foaming check.
C. pH check 6.0 - 8.0 distilled water only, with SR-1, 9.0 - 9.6 (50% solution).

Annual Requirements

3. Water System

A. Clean out core of liquid-to-air heat exchanger units.

4. R.F. System

A. Annual time domain reflectometer sweep of coaxial transmission line.

5. Klystron Beam Power Supplies

A. Check electrical terminals on supply input and circuit breakers for tightness.
B. Analyze power supply oil sample for contamination and high voltage standoff.

7. System Sweep

A. Perform spurious and harmonic energy check using procedure mentioned earlier.

9. High Voltage Beam Contactors

A. (For contactors requiring it;) Annual manufacturer's service representative call.

2-3 Year Intervals

19. Tower

A. Re-lamp, re-paint, plumb and tension (as required).

Gas Testing Klystrons

from an article by Colin Erridge, Varian Associates

A test for vacuum integrity should be performed on spare klystrons approximately every 90 days. Also, if you have a questionable klystron in which you suspect that degraded or intermittent performance might be attributable to the presence of gas in the tube, this procedure can be useful. In the gas-checking procedure outlined here, the electron gun of the klystron is used as a triode ionization gauge.

The equipment required for this test includes a digital voltmeter (DVM) of at least 11 Megohms resistance, one 45V battery, three 67.5V batteries (connected in series to provide 202.5VDC), a 110 Megohm 0.25 Watt resistor, and, possibly, a DC milliammeter with 0-5 mA or 0-10 mA range. (A single digital multimeter (DMM) fitting these specifications may be used in lieu of both meters, because they are not required simultaneously.)

To avoid the possibility of contaminated results from ground loops, ripple current and EMI, use batteries instead of AC supplies here. Current drain on these batteries will be low, so a single set should serve for many such tests.

Set up the test rig as shown in Figure 1, keeping all connecting leads as short as possible. Use an outboard supply of the transmitter's for the klystron heater. In the latter case, disconnect the negative high-voltage lead from the klystron's cathode.

Begin observations after all connections have been made, but <u>before</u> applying heater voltage. Verify that the DVM reading is near zero and stable. Body motion near the tube or test rig may cause some fluctuation. If there is a significant meter reading, check and clean all connections, wipe exposed ceramics with alcohol and look for any leakage paths in the test setup. Once the meter reading has been reduced to a small and steady value, note any remaining leakage current for subtraction from later measurements. Then apply the heater voltage, allowing five to 15 minutes for cathode warm-up.

During the warm-up time, observe that the DVM reading will typically rise, come to a peak value, fall off a bit, then stabilize. A steady reading of less than 0.1V on the DVM indicates a gas current below 0.01 mA, denoting an excellent vacuum, within the klystron under test. Vacuum integrity is considered satisfactory with DVM readings of less than 5V, corresponding to gas currents up to 0.5 mA. Measurements of 5V or more show that (if the tube is sitting as a spare) the tube should be put into service for a few days to reduce its gas current below 0.5 mA. Once spare tubes have been reconditioned in this manner, they should be returned to storage but remain on the test schedule. Keep written records of all tube checking and reconditioning.

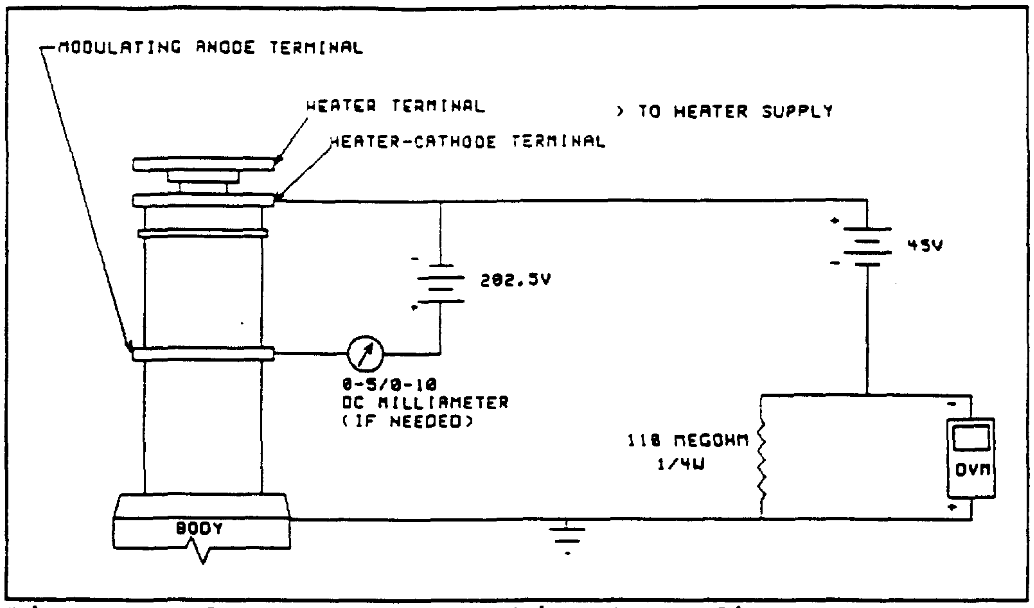

Figure 1 Klystron gas-checking test diagram.

In some cases, no reading will be seen on the DVM. To verify that this is the result of an extremely good vacuum, and not a fault in the test, the DC milliammeter or DMM in series with the 202.5V battery is used, as shown in Figure 1. For this test, the DVM, its resistor and the 45V battery may be disconnected, but the heater supply should be left up and running. A good vacuum is verified by a milliammeter reading between 1 mA and 4 mA.

While performing this test, never energize a klystron heater for more than 30 minutes without some auxiliary forced-air cooling.

Electron gun leakage

Klystrons that have been in operation for a while may be susceptible to high-voltage breakdown faults when they are moved from visual to aural operation, or from continuous to pulsed service. With either of these moves, the range of potential that the tube encounters is greater than what it has been used to, and this can cause internal arcing. A build-up of electrical leakage between elements is a normal part of tube aging, but the process can be slowed by reducing filament voltage.

High-potting, the application of a high DC potential across a klystron's elements, can be used to check electron gun leakage and to recondition these elements in many cases as well. The only equipment needed is a continuously variable DC supply with a range of 0-30 kV; its output must be current-limited to a 5 mA maximum.

To perform the operation, turn off the klystron's heater and give the cathode an hour or two to completely cool off. Then connect the negative terminal of the high-potter to the heater-cathode of the klystron, and the positive ground terminal to the modulating anode. Observe the leakage current drawn from the supply and slowly increase the voltage of the supply's output.

Stop increasing the voltage when the leakage current reads approximately 2 mA. Wait for it to drop or "burn-off." Then continue to increase voltage, holding each time the 2 mA level is reached. Repeat until the voltage of the supply is equal to the normal operating voltage of the klystron. At this voltage, try to burn off leakage current to the 200-400A range and then stop.

Now reconnect the negative terminal of the supply to the modulating anode of the klystron, and move the positive ground to the tube body. Repeat the above process to check and reduce leakage between the two elements.

Klystron Troubleshooting Guide
Symptoms and Causes

Symptom	Cause
High Body Current	1. Magnet current set too low.
	2. Magnetic materials too close to tube.
	3. RF drive power level set too high and tube is operating in overdriven region.
	4. Poor beam optics due to low heater voltage.
	5. Centering plate (external cavity tubes only) improperly adjusted.
	6. High DC power input resulting in excessive body and/or cathode current and high body/collector temperatures.
Body Current Trips	1. High voltage arc causing momentary current surges.
	2. Body/collector short (see body/collector short symptom and cause).
Cathode Body Current Overload	1. Loss of vacuum. Perform gas test and check vacuum by high-potting.
	2. High voltage arc causing momentary surges.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Loss of Vacuum	1. Check for heater current greater than 2 amps high.
	2. Crack in output window or ceramic.
	3. Tuner or tuners overheated.
	4. Collector overheated.
	5. Body section overheated.
Low Output Power	1. Low beam current.
	2. RF drive power level set too low.
	3. Tube not properly tuned.
	4. Improper magnetic field.
	5. High VSWR between klystron and load.
	6. Output coupler (external cavity tubes only) improperly adjusted.
	7. Low heater voltage.
Low Beam (Cathode) Current	1. Heater voltage set too low.
	2. If tube is at high hours it may be at end of life.

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Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
No Beam Current	1. Beam supply malfunction.
	2. Modulating anode connected to cathode or connection open.
	3. Heater voltage off or heater open. (If the heater is open, check output window; tube may have loss of vacuum.)
	4. Check high voltage contactor and circuit breaker.
No Heater Current	1. No heater voltage at tube.
	2. Open heater.
High Heater Current	1. Heater voltage is too high.
	2. Tube is down to air (check output window).
	3. Heater may be shorted internally.
	4. External short at heater connection.
	5. On a new tube, check to see if the HK and K terminals are crossed.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Thermal Detuning	1. Water flow set too low.
	2. Tube is detuned.
	3. RF drive is set too high.
	4. Magnetic materials too close to tube.
RF Line and Klystron Cavity Arcing	1. Foreign material in RF output coaxial transmission line.
	2. High VSWR in RF output coaxial transmission line.
	3. Flange connections are poor.
	4. Output coupling (external cavity tubes only) undercoupled.
	5. Defective photocell or sense circuit giving false indication.
	6. Incorrect arc detector circuit sensitivity setting.
	7. Check tube tuning (particularly 2nd cavity).
VSWR Trips	1. RF output line breakdown. Check and repair if needed.
	2. Problem in line or antenna. Reduce power to safe VSWR point and arrange to have diplexer, combiner, line and antenna swept and repaired as necessary.
	3. Improper VSWR detector setting. Check and calibrate.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Body/Collector Short	1. Defective radiation shield.
	2. Shorted thermocouple.
	3. External fittings touching.
	4. Water leaking from collector.
	5. Low resistance water hoses.
	6. Check conductivity of coolant water itself. Contaminated water can cause low resistance path.
First Cavity Will Not Tune	1. Melted drift tubes caused from magnetic field failure.
	2. Tuner forced beyond stops (Integral cavity tubes only).
	3. Input coupling loop (external cavity tubes only) improperly adjusted.
	4. Defective input power cable.
	5. Defective input power coupler.
	6. No drive power.
	7. Bent or bad finger stock where it mates with the tube.
Output or Penultimate Cavity Will Not Tune	1. RF drive level set too high.
	2. Cavity tuned too far from driver frequency.
	3. Melted drift tubes caused from magnetic field failure.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Tube Oscillates	1. RF input and output connections not terminated properly.
	2. High VSWR in RF output coaxial transmission line.
	3. Penultimate cavity tuned too close to carrier frequency.
	4. Output coupling loop (external cavity tubes only) undercoupled.
Narrow Bandwidth	1. High VSWR in RF output coaxial transmission line.
	2. Improper tuning of tube.
	3. Defective cavity loads.
Coolant Overtemp - Body, Collector and/or Magnet	1. Water impure, flow too low or coolant channel blocked.
	2. Inlet coolant temperature too high.
	3. Coolant contaminated.
	4. DC input power too high.
	5. Defective metering.
	6. Improper magnet operation causing defocussing of beam which also causes body and/or collector overtemps.
	7. Excessive steam pressure (steam transmitters only) causing back pressure and insufficient collector cooling.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Coolant Overtemp (Cont.)	8. Check heat exchanger coils (bottom) for blockage of air flow.
Low Gain	1. Tube is improperly tuned.
	2. Beam voltage is set too low.
	3. Improper magnet current.
Abnormal or Nonsymmetrical Bandpass Response	1. RF drive level set too high.
	2. Cavities improperly tuned.
	3. High VSWR in output coaxial transmission line.
	4. Improperly aligned driver.
	5. Improper adjustment of load couplers (external cavity tubes only).
AC/DC Overloads (Internal Arcing)	1. Transient in power supply.
	2. Heater voltage set too low.
	3. Beam voltage set too high.
	4. High VSWR in output coaxial transmission line.
	5. Tube down to air.

Klystron Troubleshooting Guide
Symptoms and Causes (Cont.)

Symptom	Cause
Collector Runaway (Integral Cavity Tubes Only)	1. Contaminated Coolant 2. Beam input power too high. 3. Weir level too low. 4. Back pressure in steam line.
Sync Compression Problems	1. Penultimate cavity too close to visual carrier frequency. 2. DC input power too low. 3. RF drive set too high.
Sync Ringing	1. Magnet current misadjusted. 2. Output line mismatch. 3. In BCD pulsed tubes, add a .01 uf capacitor from HK to ground.
Video Flashing	1. Defective finger stock (external cavity tubes only). 2. Arcing in modulating anode resistor causing fluctuations in beam current. 3. Poor connection in modulating anode or cathode wires.

System Induced Tube Failures

Failure	Check For
Open Heater	1. Broken tube ceramic. 2. Value of heater voltage at heater terminals. 3. Insulation breakdown of heater supply to ground. 4. Heater supply transients.
Broken Output Ceramic or Window	1. Foreign materials in RF output coaxial transmission line. 2. High VSWR in RF output coaxial transmission line. 3. Poor flange mating. 4. Mechanical stress at tube ceramics. 5. Damaged components in coaxial transmission line. 6. Malfunction of protective system, i.e., reflected power (VSWR) monitor or photodetector. 7. Loss of cavity cooling air (external cavity tubes only).
Melted Drift Tube	1. Discoloration of the paint around the body. 2. Excessive drive power. 3. Low or no body coolant flow. 4. Body coolant inlet temperature too high. 5. Inadequate magnetic field. 6. Defective power supply circuit breakers.

System Induced Tube Failures

Failure	Check For
Broken Penultimate Cavity Ceramic (External Cavity Tubes Only)	1. Penultimate cavity tuned at or through resonant frequency to a lower frequency. 2. Excessive drive power. 3. Loss of cavity cooling air.

Bibliography of Sources and Suggested Reading

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